Virtual Central approach of PV string inverters – a cost benefit

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Compared to the traditional mounting arrangement where the inverter is fixed decentral at the end of each PV string the so called virtual central offers many benefits. The obvious advantages of centrally installed PV string inverters are higher flexibility in PV system design, suitability for larger PV modules, easier access to the inverters for maintenance and operation purposes, faster installation and commissioning and, most of all, superior yield and an improved performance ratio.

But what about the cost exposure of such an arrangement? This article provides a comparison of the overall system costs and shows that virtual central layouts can be the cost-effective solution.

Virtual central layout

For bringing the power generated by the sun to the grid the following key components are needed:

- PV modules as DC power generators,
- DC collectors (DC combiner boxes or several DC inputs of inverters),
- Inverters to convert the generated DC power to AC,
- AC collector to connect the inverter outputs to the transformer,
- Transformers to step-up to the grid voltage level,
- Ring Main Unit switchgear to connect to the feed-in point.

There are two ways to place the string inverters in the overall PV plant layout: Either decentralized or distributed in the PV field at the end of each string, or alternatively at one central location within the PV plant (typically adjacent to the transformer station).

The following image provides a schematical overview of the virtual central approach:

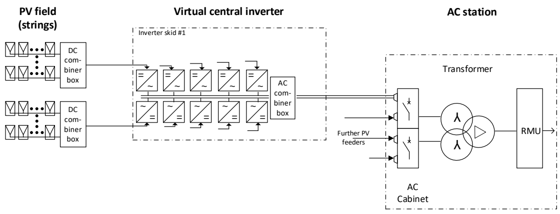

Fig.1: electrical overview

An example of an actual installation is shown in this picture:

Fig.2: virtual central inverter solution

The inverters are mounted on a rack. Underground cabling connects the inverters to the transformer station.

The virtual central approach is not only interesting for ground-mounded utility PV plants, but also for larger commercial and industrial (C&I) applications. Here, the PV modules are typically installed on the roof. Using the virtual central approach, however, the inverters can be placed on ground level or in a special service room for easy accessibility. This means the "fireman's switch" is close to the inverter and the power flow can be interrupted in case of emergency without the need to access the roof.

Furthermore, a central placement of the inverters also benefits the service effort. The equipment to be maintained can be found in one spot instead of it being distributed all over the PV field. Particularly for larger utility-scale PV plants this factor cannot be neglected.

System comparison approach

Comparing the overall cost situation between a decentralized and a virtual central approach, a system price comparison is needed. To do this with a practical orientation a PV system has been designed based on state-of-the-art components available today. Plant design and system component engineering are calculated with the simulation program “PV planet”.

The decisive factor for a virtual central approach is the inverter type. Only inverters with a single DC input, supplemented by a DC combiner box, can be used to create a virtual central layout. Inverters with numerous DC inputs, such as multi-MPPT devices, are not suitable for a virtual central layout since they require to be mounted close to the individual PV string.

The stringing of the PV modules is typically optimized to match the ratings of the applied inverters. The simulation below looks at both topologies – virtual central and decentralized – and considers monocrystalline 390 W PV modules.

Applied components

To get the best comparison between both layouts, a PV system of 6.0 MVA has been simulated with the following inverters:

	Decentralized Inverter	Virtual central Inverter
Power	185kVA	165kVA
DC Inputs	9	1
DC Voltage	1500V	1500V
Max. DC Current p. input	26A	183A
AC Voltage	800V	660V
Rated AC Current	3x134.9A	3x144.4A

Fig.3: inverter data

These inverters have been chosen since they are in the same power class, the major difference being the DC connection strategy.

The decentralized inverters are directly installed at the PV module substructure with two strings to one DC inverter input and connected via 3-phase underground cables to the AC station. No combiner boxes or separate inverter racks are required – only the mounting of the inverters.

The virtual central inverters are mounted on an inverter rack adjacent to the AC station. In the comparison at hand, it is even the more expensive variant with a DC combiner that has been chosen! The DC combiner box collects the output of the PV panels (for instance 30 modules per string) and is usually mounted at the substructure of the PV panels. In our simulation, a DC combiner box with 20 string inputs has been selected. The connection between the DC combiner and the inverter is via 2x1500 V DC underground cables.

The total installed inverter AC power capacity of the virtual central approach (6270 kVA) is almost the same as of the decentralized approach (6290 kVA). Due to the different inverter power ratings and the DC interfaces 34 decentralized inverters vs. 38 virtual central inverters are installed.

System CAPEX comparison

To compare the system costs between both topologies, we abstract the PV modules, substructure and transformer station since for both topologies the costs are the same. Instead, we focus on those elements which have cost differences: Basically, the electrical system between the PV modules and the transformer consists of inverters, inverter mounting, DC combiner boxes, AC cabinets, AC combiner boxes and cabling. Even if this part of the PV plant constitutes only 10-15% of the total plant costs, the savings gained through the virtual central layout are clearly noticeable.

The electrical system CAPEX comparison of both layout types – decentralized vs. virtual central – shows 10% higher system costs for the decentralized layout:

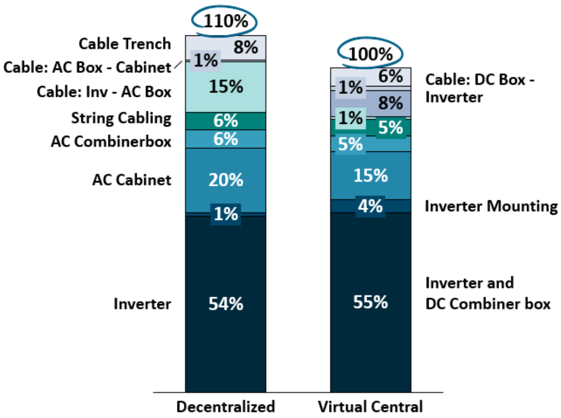

Fig.4: Decentralized vs. virtual central CAPEX comparison

More than half the overall system costs are related to the inverters. A single DC input inverter and the addition of a DC combiner box constitutes a slight cost disadvantage for the virtual central layout. However, the key cost difference between both topologies is related to the different voltage types and the associated cable connections between the PV panels and the inverters – AC for decentralized and DC for virtual central.

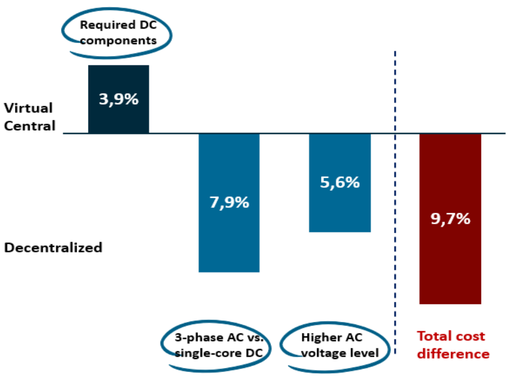

Fig.5: CAPEX differences

CAPEX differences

DC side

Inverter

The higher power density and the number of DC inputs are mainly influencing the inverter costs.

DC Combiner box

The bundling of string cables to a single connection cable inside a DC combiner box is only valid for the virtual central layout.

The virtual central layout keeps the cable losses on the DC side, unlike the decentral layout. Since in general the DC generator is over-dimensioned compared to the AC power, there is a so-called power clipping – not all energy can be evacuated. It can therefore reasonably be expected that the virtual central layout offers a superior energy yield.

The DC combiner box is located at the end of one module string and mounted on the PV module rack, meaning no additional racks are necessary. However, if the plant layout requires the DC combiner boxes to be placed separately, this can also be realized.

There are modern cabling systems available that completely put away with the need to use DC combiner boxes. The CAPEX costs for virtual central layouts can thus be reduced even further.

Alternatively, monitoring functions can be included in the DC combiner box, making a smart box out of it. This reduces the cost advantage but offers additional functionality.

Inverter mounting

The inverter mounting costs are 3% higher for the virtual central approach due to the quantity of inverters.

Cabling

String cables

The string cables are mainly depending on the number of PV modules, the selected voltage and their connection. Typically, XLPE cables with a copper conductor of small diameters from 4...8 mm² are used.

Cable DC box to inverter

Here lies the major difference of the overall system design. This cable is not applicable for the decentralized solution where the string cables are directly connected to the inverter; it represents, however, the main cable for the virtual central application. Single core cables rated for 1500 V DC bring at a maximum 165 kVA to the centralized inverters. Next to the electrical parameters the design of the DC cables depends on the soil conditions and the thermal soil resistivity.

The cross-section of the PVC sheathed aluminum cables (NAYY) depends on the maximum permissible current carrying capacity. In our example this results in a DC conductor cross-section of 150 mm².

Cable inverter to AC box

A three-phase bundled system with PE conductors is needed to bring the power at 800 V AC to the AC station. For these long cable distances PVC insulated aluminum cables (NAYY) are used.

Despite the lower current carrying capacity, a thicker cable needs to be applied for the AC cables. The conductor cross-section of the DC cable has been 150 mm², for the AC conductor it needs to be 240 mm².

The relative current carrying capacity decreases with an increasing conductor cross-section. However, the load capacity values are always higher for single-core cables than for bundled AC cable systems.

Therefore, a twofold disadvantage for the AC cable pricing occurs: A thicker cable conductor is required and at the same time the AC cable system pricing is proportionally higher than for DC systems.

Higher material and insulation efforts result in an up to five times higher pricing for the AC cable of the decentralized solution compared to the DC cable in the virtual central solution.

Cable AC box to cabinet

Special cables (NSGAFÖU) connect air laid e.g. the inverters to the AC box at the rack at a maximum length of 2m or the AC box to the AC cabinet. The highly flexible, double insulated cables with copper conductors and different rubber compounds are high in price but are only needed in low quantities compared to the overall system.

A slight benefit for the decentralized solution can be seen. However, this is only related to the applied higher power rating caused by the higher AC voltage level and is not related to the installation type.

Cable trench

The main cables are all directly buried into ground. The simulation is based on the following environmental conditions:

Ground thermal resistance	2.5K m/W
Ambient temperature	30°C
Soil temperature	25°C
Degree of utilization	0.7

Fig.6: environmental conditions

Having a slightly lower number of decentralized inverters, the total length of the cable trenches is approximately 10% shorter. However, laying three-phase cables is more cost-intensive and results in a slight disadvantage in the decentralized pricing.

AC side

AC combiner box

The lower number of connected decentralized inverters indicates a lower cost impact. However, the higher AC voltage level turns this cost benefit into a slight cost disadvantage.

AC cabinet

The costs for the AC cabinet are driven by the type of protection for the AC cables against potential failure currents, number of connections, nominal AC current and mainly the AC voltage level itself. The 800 V AC for the decentralized layout has a significant cost impact. However, such components are not industrial standard; in case that spare parts are needed the local distributor will most likely not have them in stock.

Impact DC/AC ratio

This section is dedicated to the question to which extent a higher DC/AC ratio impacts the pricing. The above CAPEX difference (fig. 5) has been based on a DC/AC ratio #1 as of the following table:

	Decentralized Inverter	Virtual central Inverter
Inst. Inverter Rating	6290kVA	6270kVA
Inst. Generator Rating	6365kWp	6447kWp
DC/AC ratio #1	101.2%	102.8%
Add. Generator Rating	1196kWp	1290kWp
DC/AC ratio #2	120.2%	123.4%

Fig.7: DC/AC ratio

An increase of around 20% leads to a ratio #2. The key difference by increasing the DC portion of the DC/AC ratio is related to the additional installed PV modules, resulting in an adaption of the AC and DC cabling (modified arrangement and higher DC current rating).

On the one hand the cable length increases based on the layout arrangement, driving the costs for cables and the cable trenching.

On the other hand, an increase of the generator output drives a higher DC current. As a result, the required conductor cross-section raises up to 20% on average. However, the generator power increase has no effect on the cross-section of the AC cable, since the maximum inverter output current is the determining factor of the AC cable cross-section which remains unchanged.

Taking above factors into account the cost increase “gained” by the additional generator power is 1.7% for the decentralized layout and 2.7% for the virtual central arrangement; in other words, the delta is a 1% benefit on the part of the decentralized configuration. The overall price advantage of the virtual central arrangement reduces to 9%.

As a summary of taking the DC/AC ratio impact into consideration it can be said that the virtual central layout remains the more cost-effective solution even for plant layouts with a DC/AC ratio of 120%...150%.

Interaction with high power PV modules

PV modules with higher power ratings are getting more and more available. Accordingly, the DC current per string increases.

Typically, two strings are connected to one MPPT current input of a decentralized inverter. For example, the maximum DC current for the inverter described above is 26 A. If the inverter DC inputs are fully utilized, a maximum current per string of only 13 A is possible. If it is intended to install high power PV modules (500+ Wp) with DC current ratings of >13 A, only one of the two DC inverter inputs can be utilized.

Consequently, fewer PV modules can be connected to the inverter. The corresponding output therefore demands for more inverters to be installed.

Take as an example a PV module with 17.5 A DC current occupying 9 DC MPPT inputs totaling 157.5 A. The inverter in the virtual central application has a maximum DC input current rating of 183 A, allowing 10 strings to be connected via the DC combiner box to the inverter.

Also, bi-facial panels typically offer higher currents due to the rear side irradiation contribution.

Single MPPT inverters are thus still offering state-of-the-art performance and allow a limitless use of high-power modules or bi-facial modules.

Outlook

The present article emphasizes the potential cost savings of approx. 10% on the electrical infrastructure inside the PV generator for a virtual central PV plant arrangement based on string inverters.

Beside the CAPEX reduction, the question to be answered is: Do I get the same generated power fed into the AC system also out of it and similarly into the revenue stream?

Preliminary yield calculations show that a virtual central layout offers superior yield under many circumstances.

More details are addressed in a separate paper related to the yield comparison between decentralized installed multi-MPPT inverters vs. single-MPPT devices in a virtual central arrangement.

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